GEOLOGY OF THE WYND MAP-AREA

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THE GEOLOGY OF THE WYND MAP-AREA, JASPER, ALBERTA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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by

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ABSTRACT

The Wynd map-area is underlain by a sequence of six argillaceous and arenaceous units whose lithology and sedimentary structures suggest deposition in the topset region of a delta. These strata lie near the top of the lower part of the Miette Formation which, by stratigraphic position, is correlated with the Upper Precambrian Hector Formation of the Bow Valley and the Horsethief Creek Formation of the Western Cordillera of British Columbia. The composition and size of detrital minerals in the Miette indicate it was derived from an igneous, pegmatitic and metamorphic source which, as suggested by sedimentary structures, lay to the east. The coarseness and low degree of rounding of the detritus may mean that the source, lying close to the edge of the craton, was not far from the deposition site and was of at least moderate relief.

Pebble-size grains of albite in the Miette Formation commonly show chessboard twinning. The chessboard pattern is formed by the (001) cleavage truncating albite twin lamellae and appears to be the result of post-depositional stress.

Rocks of the Wynd map-area have undergone folding, minor faulting, fracturing and metamorphism, presumed to have taken place during the Laramide orogeny. Eight nearly symmetrical folds account for most of the crustal shortening. Fracture cleavage, studied around the nose of one syncline, is parallel to the axial plane, suggesting it originated from reorientation of mineral grains to form a plane of weakness, rather than from a simple shear. A study of joints throughout the area yielded a pattern too complex for reliable interpretation. The writer believes that

a joint study must be confined to a single well-exposed fold, where the number of variables and their effects are at a minimum, before a reasonable interpretation is possible. The metamorphic minerals present fall within the quartz-albite-muscovite-chlorite subfacies of the greenschist facies.

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INTRODUCTION

The Wynd map-area (fig. 1) is located in the Main Ranges of the Canadian Rocky Mountains, 2.5 miles southwest of Jasper townsite, Jasper National Park. At this latitude the Pyramid thrust fault serves as the dividing line between the Main Ranges to the west and the Front Ranges to the east. The map area lies within the Pyramid thrust-sheet and is underlain predominantly by the Upper Precambrian Miette Formation. Some strata belonging to the underlying Old Fort Point Formation occur in the southwest corner of the map-area but these, along with Miette strata south of the Miette River, were not mapped.

During 7 weeks of the 1961 field season, the structure, stratigraphy and sedimentation of the Miette Formation within the map-area were studied in some detail. Aerial photographs, enlarged to a scale of 6.5 inches to the mile, served as base maps. Surficial deposits cover a large part of the area.

The Precambrian rocks of the Jasper region were originally described by McEvoy in 1898, and the term Miette was introduced by Walcott in 1913. Allan, Warren and Rutherford (1932), Charlesworth and Remington (1960), Remington (1960), Charlesworth, Evans and Stauffer (1961), and Stauffer (1961) have since carried out investigations on the Precambrian.

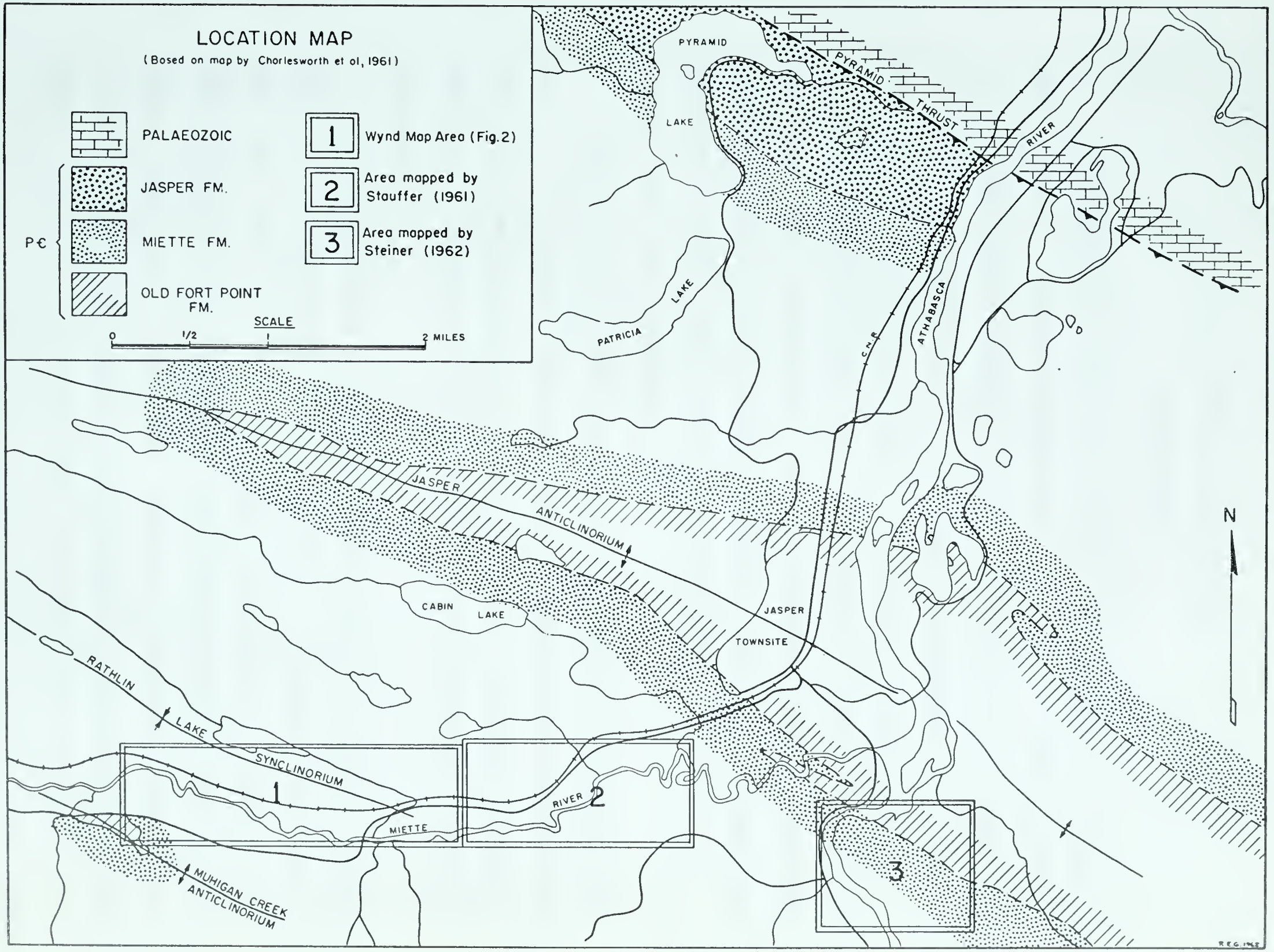

LOCATION MAP
(Bosed on map by Charlesworth et al, 1961)
PALAEOZOIC
JASPER FM.
MIETTE FM.
OLD FORT POINT FM.
Pℇ
SCALE
0
1/2
2 MILES
1
Wynd Map Area (Fig.2)
2
Area mapped by Stauffer (1961)
3
Area mapped by Steiner (1962)
PYRAMID
LAKE
PYRAMID THRUST
RIVER
PATRICIA LAKE
ATHABASCA
C.N.R.
JASPER ANTICLINORIUM
CABIN LAKE
JASPER TOWNSITE
RATHLIN LAKE SYNCLINORIUM
MIETTE RIVER
MUHIGAN CREEK ANTICLINORIUM
N

Fig. 1

STRATIGRAPHY AND SEDIMENTATION

Introduction

The Precambrian rocks in the Jasper region consist of a sequence of four apparently conformable formations. The oldest of these, the Meadow Creek, predominantly arenaceous, is overlain by argillites, limestones and breccias of the Old Fort Point. Next, the Miette consists of a lower arenaceous and argillaceous sequence, toward the top of which lie the strata of the Wynd map-area, and a predominantly argillaceous upper portion. Overlying it are the arenaceous beds of the Jasper Formation, which grade up into the Lower Cambrian Cavell Quartzite. Excluding the Meadow Creek Formation, of which little is known, the Precambrian formations are probably from 6000 to 7000 feet thick.

Walcott (1913, p. 340) described all the rocks of this region as massive grey sandstones with interbedded grey and greenish-grey siliceous shale, which he included in the Miette Formation. Charlesworth *et al.* (1960, p. 12) restricted the term Miette and named the other formations noted above.

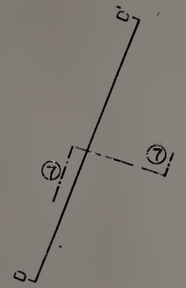
The Miette strata in the Wynd map-area (fig. 2), west of Caledonia Creek, are divisible into 6 lithologic units. The exact relationship between unit 1 and the base of the largely argillaceous upper part of the Miette Formation is not known with any degree of accuracy, but this unit probably lies some 1600 feet above the base of the Miette. The area east of Caledonia Creek was mapped as a continuation of the study by Stauffer (1961). Considering the local crustal shortening, unit 1 is probably separated by some 350 feet from Stauffer's unit 15 (fig. 2). The lower

C D

A B C D E H

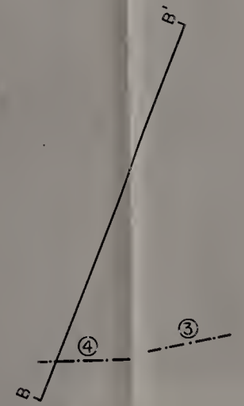
A B C D E F G H

F G H













Legend

A ——— A' Structural Cross-Sections

③ Stratigraphic Cross-Sections

B C D Letter Designation of Folds

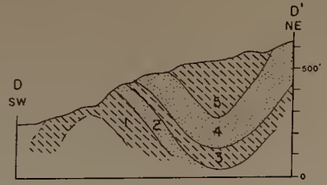


Fig. 2d



Fig. 2c

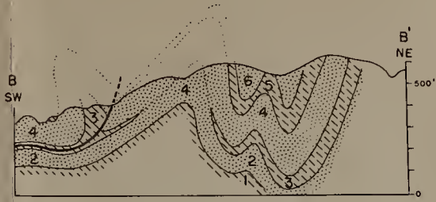


Fig. 2b

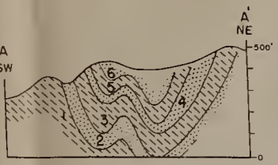
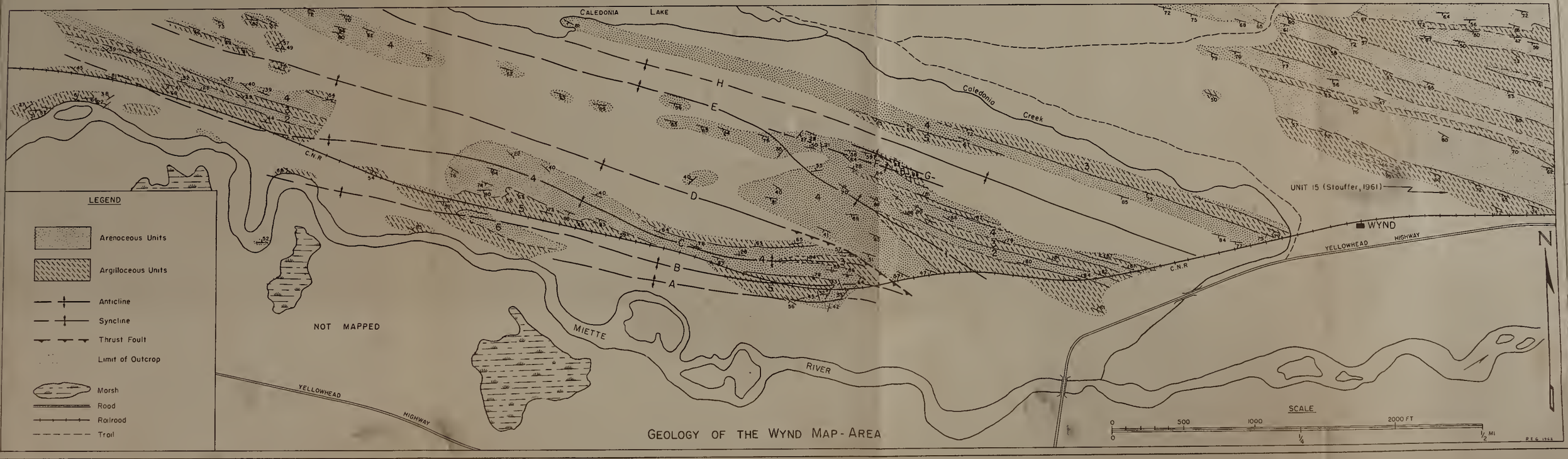


Fig. 2a

DIAGRAMMATIC STRUCTURAL CROSS-SECTIONS



GEOLOGY OF THE WYND MAP-AREA

Fig. 2

1500 feet of the Miette Formation have been described in detail by Remington (1960), Stauffer (1961) and Steiner (1962).

Arenaceous Units

General. Pebble conglomerate, sandstone and common interbeds of siltstone and argillite comprise the arenaceous units. The bedding thickness varies from 1 inch to several feet, but is most commonly about 2 feet. Regardless of thickness, a bed rarely persists along strike for more than 100 feet before it lenses-out or grades into another lithology. Using the terminology of Crook (1960, p. 426) the typical lithologic type is that of a sub-labile, coarse-grained lithic sandstone. The rocks are usually very hard.

Sedimentary Structures. Graded bedding of the waning current type, cross-stratification, load casts and scour-and-fill structures are common in the arenaceous units, whereas flute casts and ripple marks are rare (plate Ia-c, plate II). The cross-strata, having less matrix than the surrounding rock, are lighter in colour which makes them conspicuous. The load casts shown on plate IIa have a subparallel alignment which may indicate that they are flute casts. These sedimentary structures have been described in detail by Stauffer (1961, pp. 6-13) from observations made in the immediately underlying strata. Except for graded bedding which is not as conspicuous in the area under study as in the older Miette strata mapped by Stauffer, there are no significant differences in the sedimentary structures present.

Colour, Grain Size and Composition. On weathered surfaces, the arenaceous units range in colour from light greyish-brown to reddish-brown, while

PLATE I

a. Planar cross-bedding in a coarse-grained sandstone - unit 4; 4000 feet west of Caledonia Creek. (Cross-bedding terminology is after McKee and Weir, 1953).

b. Planar cross-bedding in a coarse-grained sandstone - unit 4; 2500 feet west of Caledonia Creek.

c. Trough cross-bedding, same location as above.

d. Cavernous weathering in sandstone unit 4, one mile west of Caledonia Creek.



a



c



b



d

PLATE II

a. Subparallel load casts on the base of a sandstone bed in unit 2; one-quarter of a mile west of Caledonia Creek.

b. Scour channels on the top of a coarse-grained sandstone bed in unit 4; one-half of a mile west of Caledonia Creek.

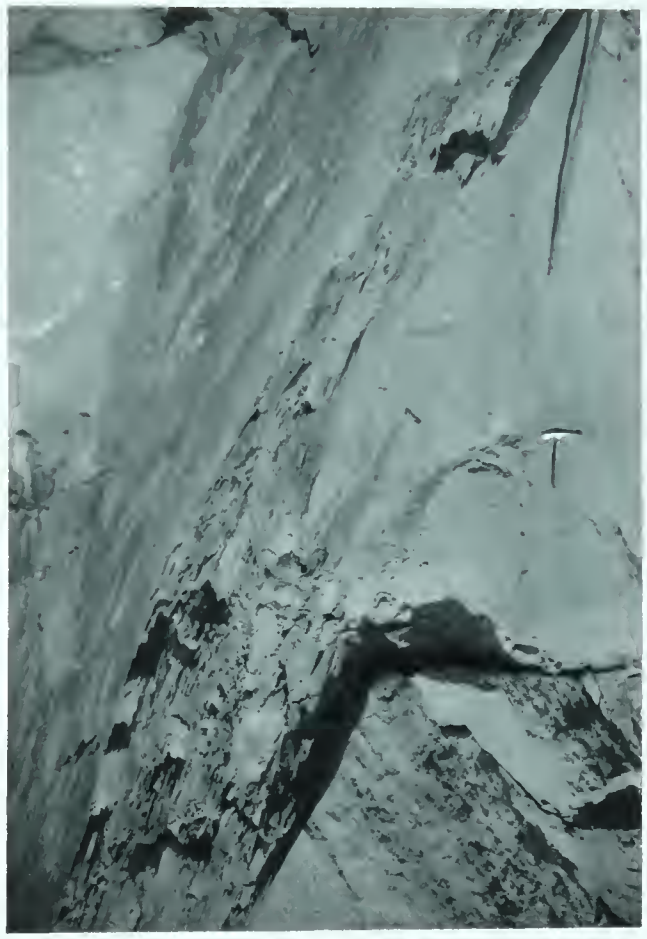
c. Small-scale flute casts on a thin argillite interbed in sandstone unit 2, same location as a.

d. Intertonguing of sandstone and argillite, 150 feet west of Caledonia Creek, unit 4. The argillite thins from 3 feet at the top of the photograph to one foot at the bottom.

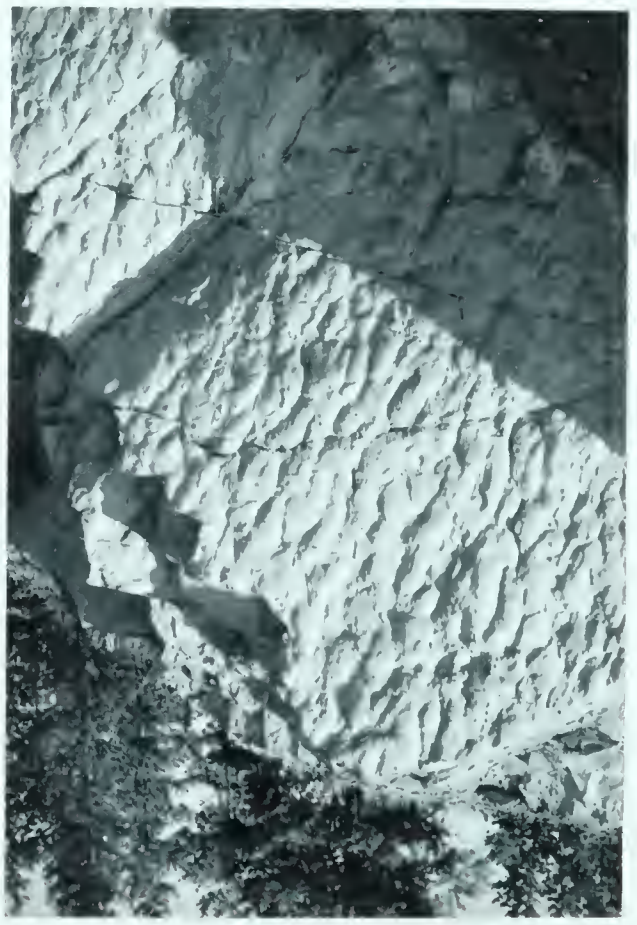
c



d



a



b



fresh surfaces are usually some shade of light grey. The preponderance of brown weathering contrasts with the arenaceous beds lower in the Miette Formation which tend to be greenish-grey. The average grain size falls in the coarse sand range (1-2 mm), but fine pebbles which average 4 to 5 mm are common. Coarse angular rock fragments are locally common. In all grain sizes, subrounded to subangular grains form the greatest percentage of the rock. The low degree of rounding is expected since the arenaceous beds are, at best, only moderately well sorted. Quartz, rock fragments, micaceous minerals, carbonates and heavy accessory minerals are the main coarse constituents of the sandstones and conglomerates. Ten to twenty-five per cent of the rock is matrix composed of quartz silt, fine-grained muscovite and chlorite.

Four varieties of quartz-plutonic, vein, recrystallized metamorphic and stretched metamorphic - make up 60 per cent of the sandstone and conglomerate grains. In some cases, these show the effects of pressure solution (overgrowths and sutured contacts), and diffuse boundaries as a result of replacement by matrix. Single and composite grains of probable plutonic quartz are the most abundant.

Plagioclase feldspar, with an average composition of An_5, forms approximately 10 per cent of the arenaceous rocks mapped by Stauffer (1961, p. 17), but only one sample of the present study, a fine-pebble conglomerate, in unit 2, yielded recognizable feldspar. It commonly shows albite and chessboard-albite twinning (see p. 19) and extinction-angle determinations indicate it to be plagioclase with a composition of An_5. Approximately 15 per cent of this conglomerate is composed of an intimate

mixture of chlorite and muscovite closely resembling the matrix of the rock and representing altered plagioclase. Similar mixtures of chlorite and fine-grained muscovite showing outlines of detrital grains, were observed in some of the other coarse-grained rocks. Some or all of these grains may have been feldspar that is now completely replaced, but in any case it appears to be less abundant than in the arenaceous units lower in the Miette Formation.

Micaceous minerals - muscovite, biotite and chlorite - usually make up 1 to 2 per cent of the phenoclasts, but may be present in amounts up to 5 per cent. Muscovite occurs as detrital grains, as an alteration product of biotite and feldspar, and as minute grains, probably metamorphic, in the matrix. Biotite is never common, and is almost always altered. Chlorite, the most abundant micaceous mineral, forms a large part of the matrix and appears as an alteration product of biotite and feldspar. It is usually pale green and commonly shows anomalous dark blue interference colours.

The sandstones and conglomerates usually have less than 5 per cent cement, which is most commonly calcite although some siderite and dolomite may also be present. At one locality, a mosaic of fine-grained dolomite cement makes up approximately 25 per cent of the rock. Cavernous weathering (plate Id) may develop where there is a high percentage of carbonate cement in the rock, but in these fairly rare instances, granular disintegration is more common. Euhedral grains of siderite, 50 to 75 microns long and in many cases rimmed with limonite, are scattered throughout many of the arenaceous rocks. This siderite (some of which may be ankerite), along

with calcite, has commonly replaced portions of detrital grains in the rock.

Rock fragments are sparsely scattered throughout many of the arenaceous beds but may be locally abundant. Argillaceous rock fragments having the same lithology as the argillite units (p. 24) are the most common. These are usually very angular and less than 2 inches long and a fraction of an inch thick, but may occur as large slabs several feet in length. They are most numerous in the basal part of conglomerates that overlie argillite, and appear to have been derived locally. Angular fragments of brown weathering dolomite, averaging 2.5 to 5 cm in length, are also common (plate IIIa). These fragments have less than 10 per cent quartz silt and pyrite, and although very fine-grained, in many cases contain abundant rounded structures, averaging 0.5 mm, which resemble pellets and rounded algal fragments (plate IIIb).

Heavy accessory minerals were studied from fine-grained sandstones of units 2, 3 and 4 of the Miette Formation and from a fine-grained sandstone at the top of the Old Fort Point Formation. The result of this study together with those of Remington (1960) and Stauffer (1961), gives a representative picture of the heavy mineral assemblage in fine-grained sandstones of the lower Miette Formation (fig. 3). Contamination of the heavy mineral separate by light minerals prevented an exact calculation of the percentage by weight of "heavies", but it is estimated to be less than 0.1 per cent. The non-opaque heavy minerals identified were zircon, tourmaline, rutile and apatite, typical varieties of which are shown on plate IV. Several grains of common hornblende were also observed, but these are thought to be contamination introduced during sample preparation.

PLATE III

a. Pebble conglomerate with phenoclasts of brown weathering dolomite; sample from unit 2, 1500 feet west of Caledonia Creek.

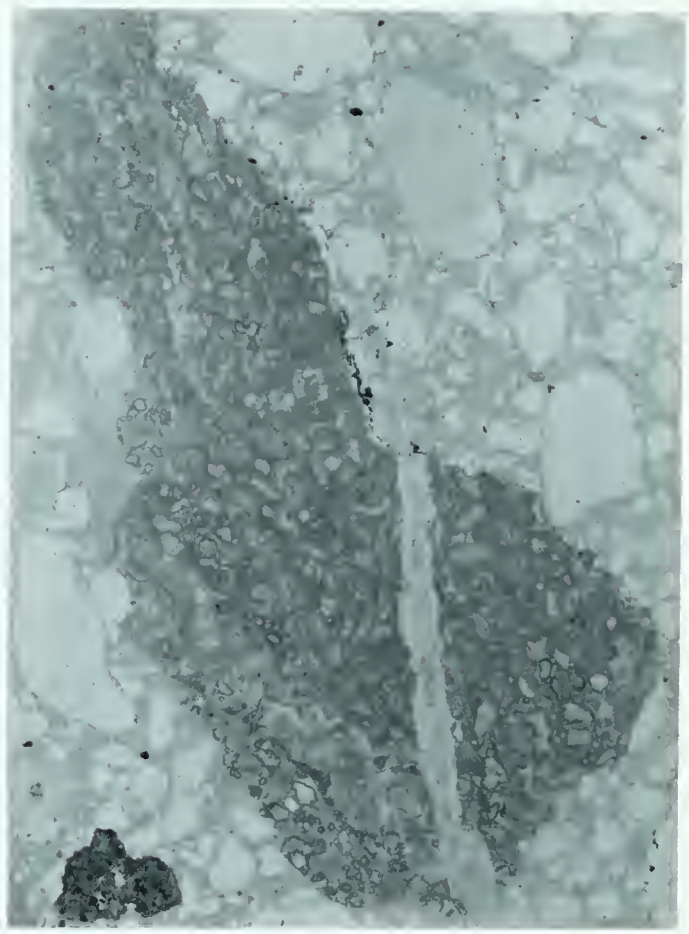
b. Thin section of a dolomite phenoclast from the above sample. The rounded structures resemble pellets and rounded algal fragments. X6

c. Photomicrograph of an albite pebble showing chessboard twinning. The (001) cleavage (up and down on the photograph) can be seen truncating the twin lamellae. X100 Crossed nicols.

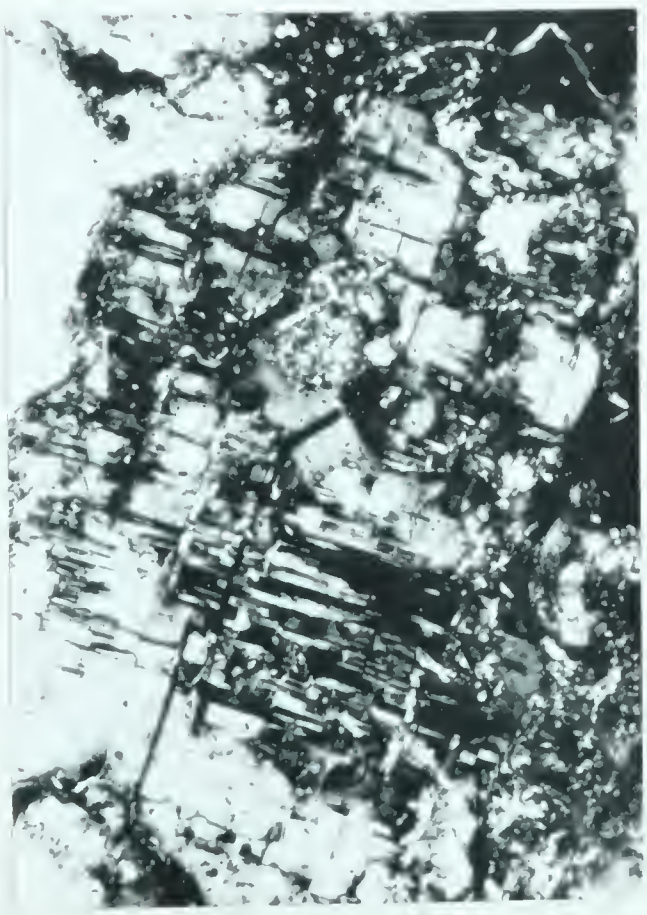
d. Same as above, X200.



a



b



c

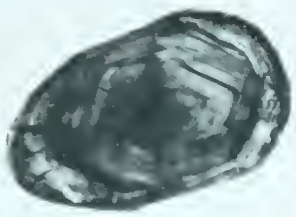


d

DESCRIPTION OF PLATE IV

Photomicrographs of typical heavy minerals, all X180

1. Zircon - pink, shows distinct zoning and rounded regrowth.
2. Zircon - pink, subhedral, elongate.
3. Zircon - pale pink zoned core with a colourless periphery, euhedral, fractures radiate from centre.
4. Zircon - colourless, large irregular globular inclusion, stubby euhedral.
5. Zircons - both grains nearly spherical, upper one is pink and weakly zoned, lower grain is clear.
6. Zircon - pink, very well rounded, weakly zoned.
7. Zircon - pink, small core, rounded regrowth.
8. Zircon (Malacon) - dark purple, subhedral.
9. Tourmaline - blue, angular fragment.
10. Tourmaline - grey, angular fragment.
11. Tourmaline - light brown, fracture terminated prism with many globular inclusions.
12. Tourmaline - light brown, fracture terminated prism with some dusty inclusions.
13. Apatite - colourless, angular, abundant small black inclusions.
14. Apatite - colourless, rounded, globular inclusions.
15. Rutile - dark amber, angular.
16. Rutile - amber, subhedral, weak diagonal striations.



1



2



3



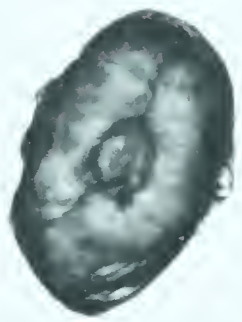
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5



6



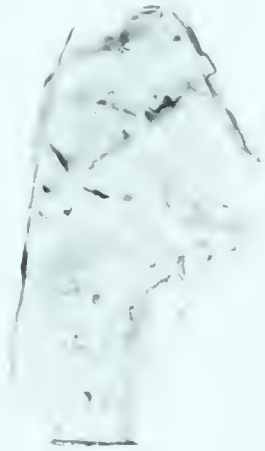
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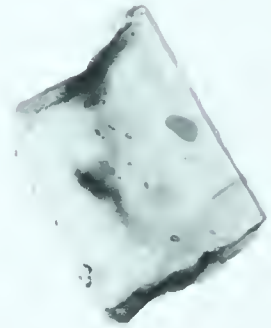
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10



11



12



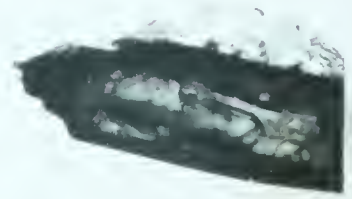
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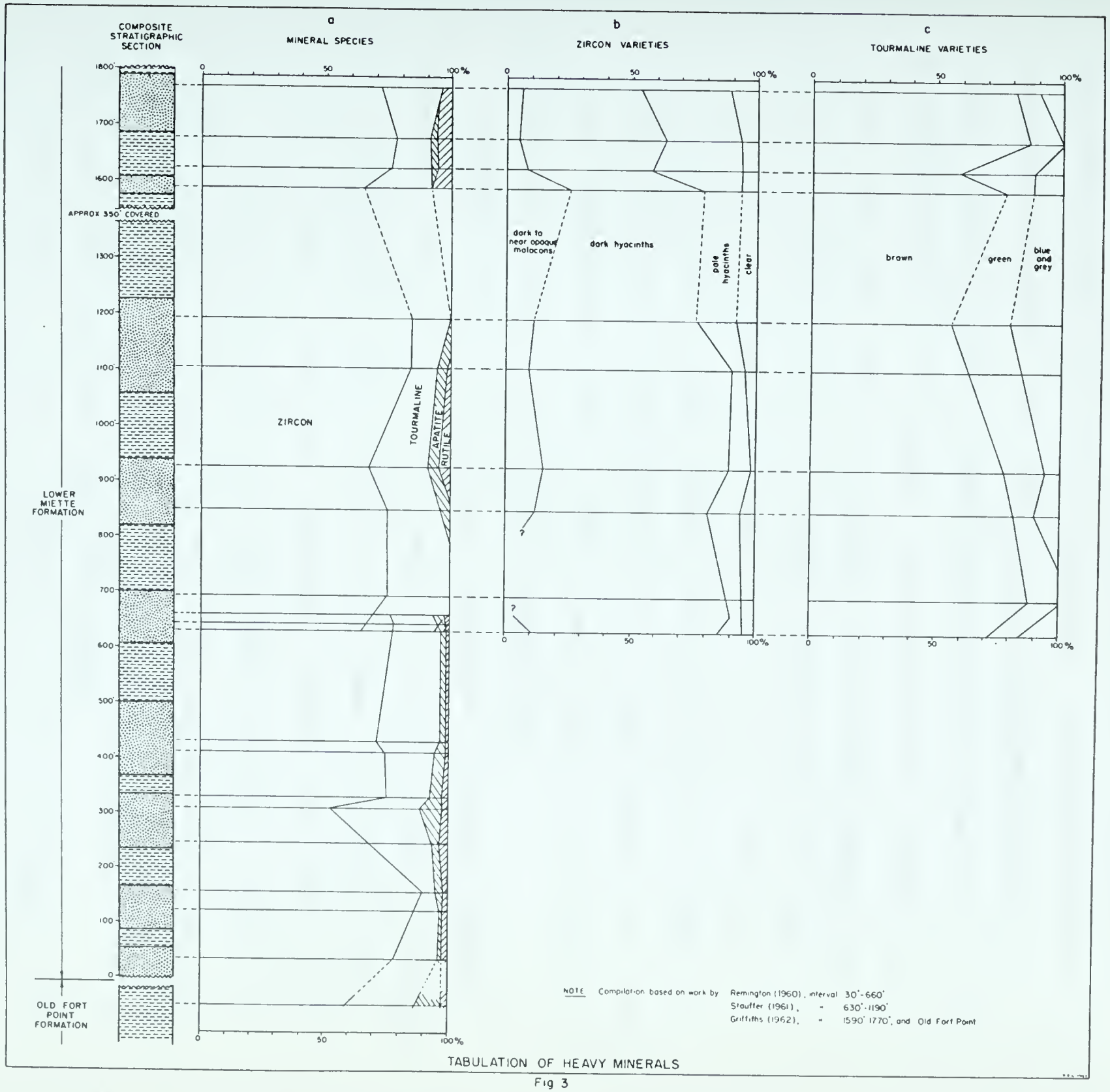
14



15



16



TABULATION OF HEAVY MINERALS

Fig 3

Zircons, the most abundant heavy mineral present, are grouped into four colour varieties: 1) clear, 2) pale hyacinths, 3) dark hyacinths, and 4) dark to near opaque malacons (fig. 3b). The longest zircon observed was 265 microns, while the average of unbroken grains was 136 microns. Some of the well rounded grains are nearly spherical and have an average diameter of 90 microns. The average width to length ratio is slightly less than 2, which corresponds to the average dimensions for zircons in sandstones, while the average length is the same as that for zircons in most sediments (Poldervaart, 1955, p. 441). Zircons are better rounded than any other mineral, 26 per cent are well rounded and rounded, 39 per cent are subrounded and 35 per cent subangular and angular. Irregular globular inclusions, zoning, rounded regrowths and fractures radiating from the centre are features commonly seen.

Tourmaline is present as fracture-terminated prisms and irregular flakes which, though occasionally rounded, are mainly angular to subangular. Grains showing basal crystal faces are less common. The average width of tourmaline prisms is 85 microns, the largest observed being 150 microns wide. The grains were grouped into three colour varieties: 1) brown of all shades, 2) green of all shades, and 3) blue and gray (fig. 3c). All varieties show strong pleochroism. Irregular globular inclusions are common while dusty inclusions occur less commonly.

Rutile occurs as amber to reddish-brown angular and subangular grains averaging 110 microns in length. Most grains show longitudinal or oblique striations and some alteration to leucoxene.

Apatite occurs as colourless or pale brown, usually angular, grains which average 95 microns in length.

Opaque heavy minerals were not studied but ilmenite, magnetite and authigenic pyrite are present. Pyrite may be locally abundant, and at least a few cubes can be seen in nearly all hand specimens and thin section, but grains rarely exceed 2 mm. Large pyrite cubes, which are common in the older Miette arenaceous rocks (Stauffer, 1961, p. 24), were not observed in the Wynd map-area.

Albite Chessboard Twinning. Albite when present in the Miette strata, commonly shows a chessboard-like pattern when viewed between crossed nicols. This twinning consists of a complex pattern of short twin lamellae which are commonly truncated at a fracture (plate III). Using a five-axis universal stage, ten plagioclase grains, showing polysynthetic twinning, from fine-pebble conglomerates of the lower part of the Miette Formation were studied. Eight of the grains are twinned on the albite law, one on the acline, and one on an indeterminant parallel law.

Among previous workers there are different views regarding the origin of chessboard twinning. Starkey (1959) reported chessboard twinning that formed during the regional metamorphism of porphyries to albite schists. Perthites in the porphyries were transformed to chessboard albite, and intermediate stages were also observed. The chessboard pattern was best developed alongside cracks in the albite crystals which prompted Starkey to propose that the twinning had been caused by strain, and would be best developed between fractures, which were regions of greatest strain. The chessboard twinning, according to Starkey, was caused by two processes: metasomatism of potash-soda feldspar into albite, and deformation. He further proposed that the chessboard pattern forms in preference to the

more normal polysynthetic twinning because the albite has taken over the lattice peculiarities of the potash feldspar. Remington (1960, p. 11, 12) reported that chessboard twinning occurs only on the pebble-sized grains of plagioclase and that sand-sized fragments are twinned in the normal manner. He attributed the twinning to stress which would have been greater in the pebbles than in the interstitial sand-sized particles. He further reported that cleavage is often exceptionally well developed in the pebble-sized grains. Stauffer (1961, p. 18), on the other hand, believed that the chessboard twinning was present in the original detrital feldspars and that albitization has been the only post-depositional alteration to occur.

The proposal of Starkey receives no support from the present study. Most commonly, the chessboard effect has been caused by abrupt truncation of the twin lamellae by the (001) cleavage plane. When not truncated in this manner, the lamellae stop at some irregular fracture or simply pinch-out. There seems to be no relationship between the chessboard pattern and the pericline twin-plane, as would be expected if the pattern were inherited from albitized microcline. Furthermore, one grain showing a relict perthite structure in which the two phases, with different orientations, are now both albite, does not show chessboard twinning.

The present writer does not agree with Stauffer that this twinning was present in the original detrital feldspar in as much as it seems unlikely that a complex structure such as chessboard twinning, could survive the recyrstallization which accompanied albitization. The fact that the chessboard twinning is commonly associated with the (001) cleavage suggests a genesis arising from post-depositional stress. When stressed, the grains of albite may tend to fracture and become twinned. A fracture plane is at

a higher energy level than the rest of the crystal, so it seems likely that twinning would be most readily generated adjacent to the fracture and tend to die-out away from the fracture. It is possible that when a plane of weakness such as the (001) is favourably oriented with respect to the stress system, the resulting strain produces a chessboard effect. Grains unfavourably oriented might simply acquire the more normal type of polysynthetic twinning.

Argillaceous Units

General. Argillite, silty argillite, siltstone and occasional interbeds of fine-grained sandstone form the argillaceous units. The strata range from being laminated to being in beds several inches thick and, while they are usually poorly exposed, appear to be more uniform and persistent than beds in the arenaceous units. The typical lithology is silty argillite.

Sedimentary Structures. Varve-like grading, from fine-grained sandstone or siltstone to argillite, is common and occurs in strata a fraction of a centimetre to several centimetres thick (plate Va). The average varve thickness is about 2 cm.

Cross-laminations are commonly observed in silty argillites and siltstones (plate Vb). The sets of cross-strata are of both the simple and trough type and rarely exceed 3 cm. in thickness.

Small scale load-casting, illustrated in plate Va, b, occurs at the base of many of the graded beds.

PLATE V

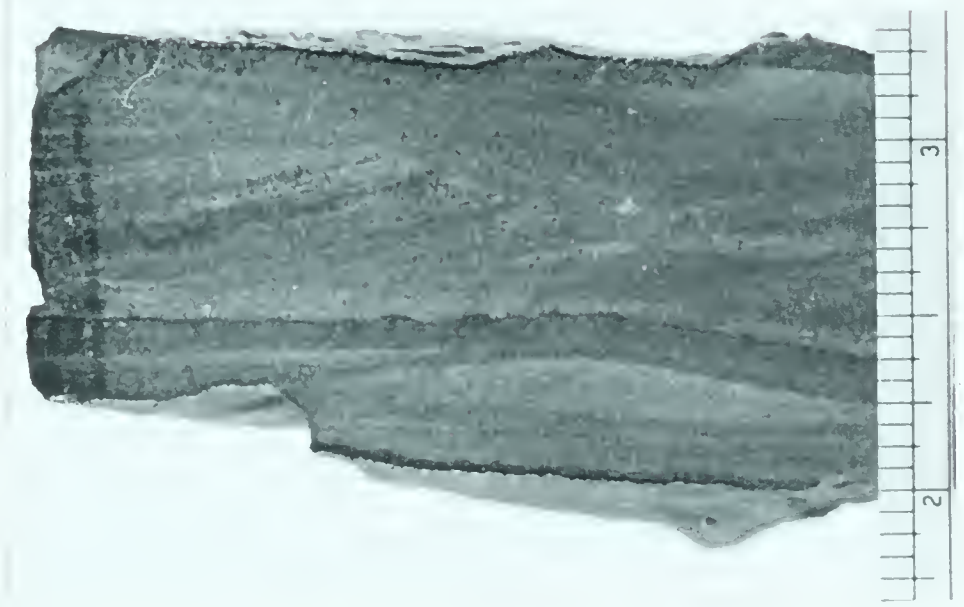
a. Varve-like bed grading from fine-grained sandstone to silty argillite. Small-scale load casts can be seen at the base of the bed, along the top of the dark band of argillite. Sample is from unit 5, three-quarters of a mile west of Caledonia Creek.

b. Trough cross-stratification in siltstone. Small scale load casts occur at the top of the argillite band that crosses the lower part of the specimen. Sample is from same locality as above.

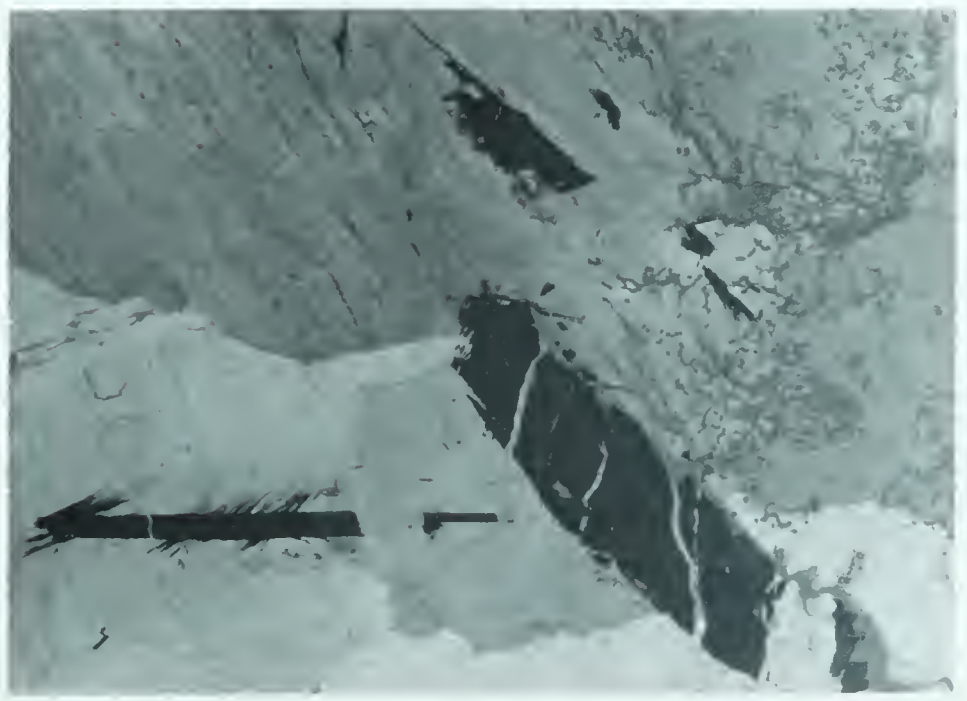
c. Subhedral rutile grains (black) in a quartz vein. Note the rutile needles associated with the grain in the lower left. The fine, grey patches in the upper left are vermicular chlorite. X12.



a



b



c

Colour and Composition. The argillites range in colour from light to dark grey and may have dark bluish-grey bands and laminations. Siltstones are usually light brown but are in places highly speckled with limonite from the oxidation of fine pyrite and siderite. Weathered surfaces are commonly reddish-brown but may be grey or light olive-green.

The argillites contain a highly variable amount of quartz silt, muscovite, chlorite, heavy minerals, and carbonate cement. Muscovite is present as detrital grains, as an alteration product of biotite and as very fine grains (probably of metamorphic origin) which, along with chlorite, form the matrix. Chlorite, as well as being an alteration product of biotite, is present in rounded grains which may originally have been feldspar. The same suite of heavy minerals found in the arenaceous rocks, is present in the argillites. They are most abundant in siltstones and fine-grained sandstones where they are, on occasion, concentrated in layers. Carbonate cement as small irregular patches occurs uncommonly.

Correlation

The rocks of the Wynd map-area have been assigned to the Miette Formation. Walcott (1913) originally applied the term Miette to those Precambrian rocks outcropping in the Miette River valley. Charlesworth and Remington (1960) restricted the term Miette to apply to the interbedded sandstones, conglomerates and argillites that overlie the argillites, limestones and breccias of the Old Fort Point Formation, and underlie the sandstones and pebble conglomerates of the Jasper Formation.

Correlation of rock units within the Wynd map-area is based on gross lithology and structural position. Good marker horizons are absent due to rapid lateral and vertical variations in lithology. For this reason the correlation shown in figure 4 is not the only one possible, but is believed to be the most probable.

Stratigraphic unit 1 of the Wynd map-area is separated from unit 15 of the Ski-Lodge Road map-area (Stauffer, 1961) by a wide covered interval. Based on the width of the covered interval and average dip of beds on either side, there could be as much as 600 feet of unfolded strata in this covered interval. However, it is likely that these strata, assumed to be argillite, are folded to some extent, so the thickness of unexposed beds is taken to be 350 feet, assuming a crustal shortening of 40 per cent (p. 34).

Stratigraphic position and lithologic similarities suggest that the Miette correlates with the Horsethief Creek Formation of the Western Rocky Mountains and the upper part of the Hector Formation in the Bow Valley. The Horsethief Creek "consists of argillites, phyllites, and slates as well as prominent successions of quartzite, pebbly and feldspathic pebbly quartzites, and quartz pebble conglomerates" (Reesor, 1957, p. 159). This description is similar to that of the Miette Formation. While lacking coarse arenaceous units, the upper portion of the Hector Formation contains dark grey argillite similar to that of the Miette, and the two may be correlative. The coarse clastics characteristic of the lower portion of the Miette Formation appear not to have been deposited in the region of the Bow Valley.

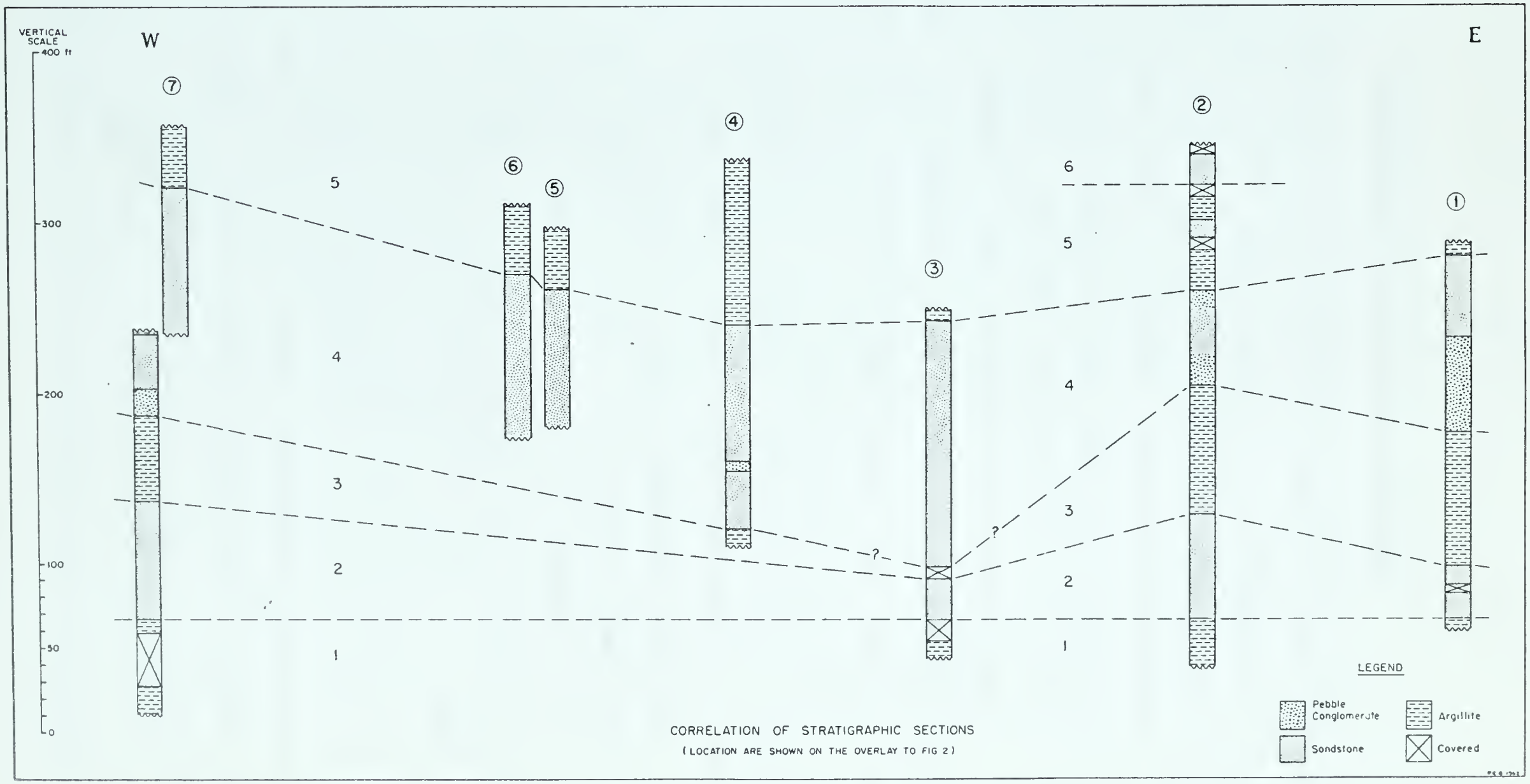

VERTICAL SCALE
400 ft
300
200
100
50
0
W
E
⑦
⑥
⑤
④
③
②
①
5
4
3
2
1
6
?
?
LEGEND
Pebble Conglomerate
Argillite
Sandstone
Covered
CORRELATION OF STRATIGRAPHIC SECTIONS
(LOCATION ARE SHOWN ON THE OVERLAY TO FIG 2)

Fig 4

Provenance and Depositional Environment

The composition and size of detrital minerals in the Miette Formation indicate that there were igneous, pegmatitic and metamorphic rocks in the source area. Quartz with slightly undulose extinction and few inclusions, typical of plutonic rocks, is present. Recrystallized metamorphic quartz, stretched metamorphic quartz, and less common metasiltstone grains indicate a metamorphic source. The large size of many quartz and feldspar grains suggest the presence of either coarse granitic rocks or pegmatites in the source area. The composition of the feldspars might mean that albite schist was a parent rock, but previous workers in the Jasper area have postulated post-depositional albitization to account for their high sodium content, which is in accordance with findings of the present study. Dark brown tourmaline, the most abundant variety in the Miette rocks, is characteristic of granites. Blue tourmaline is common in pegmatites, and since only fragments of larger crystals are present, this is their probable source. Zircons, though found in other rock types, are most abundant in acid and intermediate igneous rocks. The range of colour, size, and shape of zircons may indicate a compound source, although zoned grains are probably of igneous origin. The lack of rounded quartz grains lessens the possibility of a large amount of unaltered sedimentary rock in the source area, but well rounded zircons and those with rounded overgrowths may have been derived from metasediments. Apatite is derived largely from acid igneous rocks and pegmatites. Rutile is found in granites, pegmatites and metamorphic rocks. Magnetite and ilmenite are common accessory minerals in all igneous rocks. Small grains of detrital mica, muscovite and biotite, could

originate from either a granitic or metamorphic terrane, but large grains of muscovite (up to 20 mm), present in some coarse Miette rocks, are probably of pegmatitic origin.

In summary, the heavy minerals that could definitely establish the nature of the Miette source rocks are absent. Only the ultrastable minerals are present and these rarely point to a single parent rock-type. In general, the varieties and coarseness of the quartz, the coarse feldspar and muscovite, blue tourmaline, and the other heavy minerals, when considered together, indicate a source area containing dominantly granitic, pegmatitic, and metamorphic rocks.

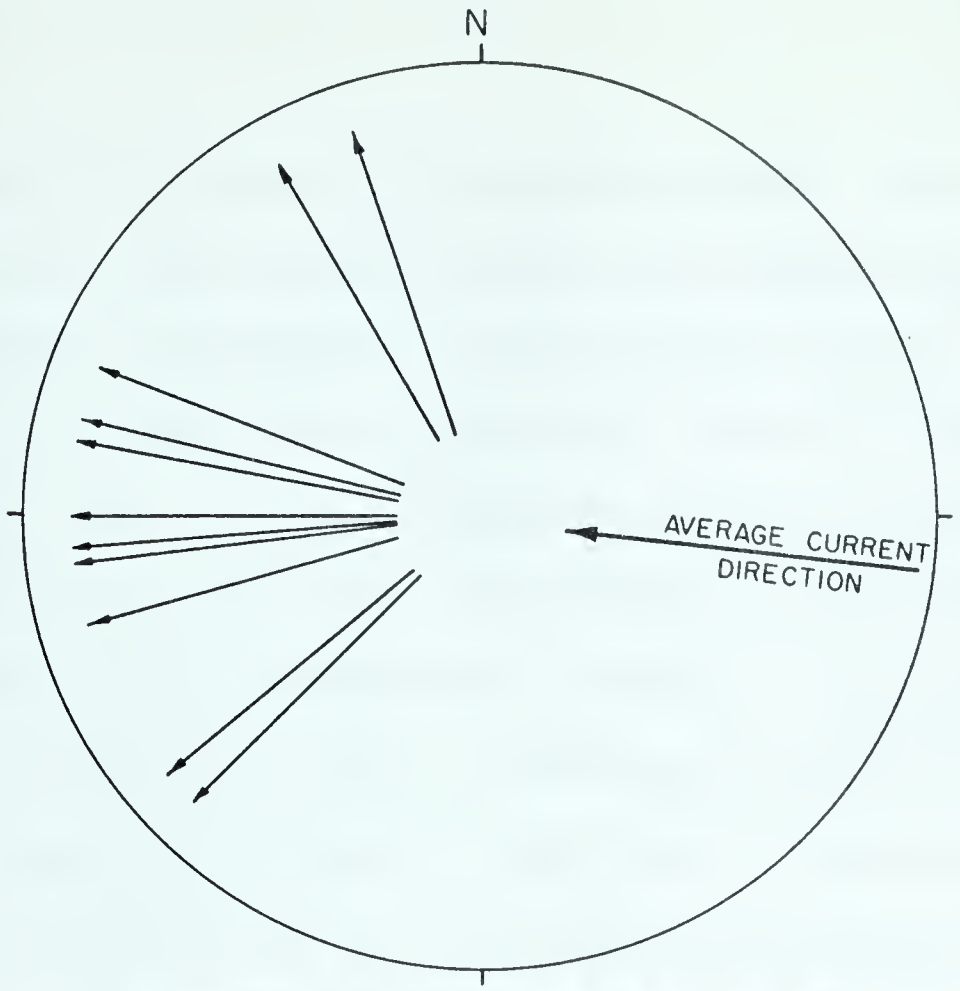
The coarse, angular nature of the detrital grains indicates a short, rapid transportation history. The source area would need to have been of moderately high relief to provide sufficient gradient to allow transportation of the coarse detritus. A terrain underlain by unroofed acid igneous bodies intruding regionally metamorphosed rocks and standing not far from the coast may have provided the Miette sediments. It appears possible that the relief of this terrain had been lowered considerably by the time the sediments belonging to the upper part of the lower Miette Formation were deposited. This is suggested by the highly altered nature of the feldspar (the state of feldspar preservation is more likely to be related to weathering at the source than to transportation).

Eleven attitudes of cross-stratification were measured over a narrow stratigraphic interval in unit 4. With the bedding rotated so that the cross-strata are represented in their original position of deposition, they indicate a source area lying to the east (fig. 5). Stream meanders could

account for the scatter of readings to the northwest and southeast, or these directions could represent components of a littoral or tidal current moving normal to the stream direction (see Tanner, 1955). A plot of 12 scour channels and 2 sets of flute casts is shown in figure 6. For the most part, these readings were taken from sandstones adjacent to those in which the cross-strata were measured. A comparison of figures 5 and 6 shows close correlation between the current directions obtained from these two groups of structures.

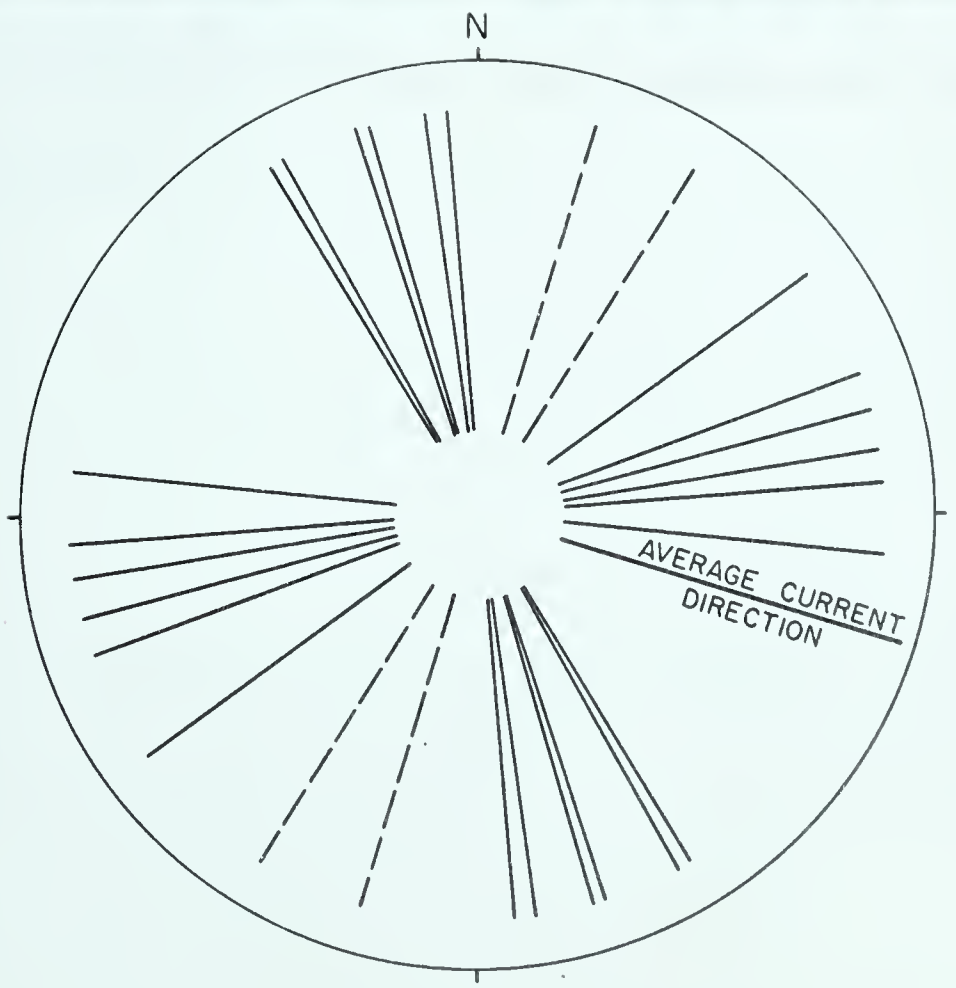
Lead-alpha dating of detrital zircons collected by Stauffer (1961) indicated an age of 1330 $\pm$ 150 m.y. An age obtained from detrital muscovite by Steiner (1962) is 1776 $\pm$ 90 m.y. Lead-alpha dates are often too small (see Silver, et al., 1961), hence the older muscovite date is probably more nearly correct. This suggests that the source lay within the Churchill province (see Burwash, et al., 1962) and may have been a subsequently eroded extension of the "Peace River High", or simply a Shield area of moderate relief on the present Alberta plains.

The depositional environment appears to have been the topset region of a delta. The characteristics of topset deltaic beds given by Rich (1951, pp. 1-20) include coarse-grained sediments (conglomerates to siltstones), cross-stratification, waning-current graded-bedding, lenticular bedding with rapid lateral and vertical change in grain size, and wavy contacts between beds--features common to the Miette rocks under study. The Miette arenaceous units probably represent distributary channel or, in some cases, barrier island deposits. Towards the top of the lower portion of the Miette Formation there is a decrease in frequency of graded bedding which



CROSS-STRATIFICATION DIP BEARINGS

Fig. 5



SCOUR-CHANNEL (12) AND FLUTE CAST (2) BEARINGS

Fig. 6

R.E.G. 1962

may indicate some reworking of the arenaceous beds. The slight decrease in average grain size towards the top of the formation may reflect a general decrease in strength of the depositing currents.

The argillaceous units may have been deposited in lagoons and inter-distributary areas. Periodic flooding of lagoonal regions may have been responsible for the varve-like graded bedding, while small-scale cross-bedding could reflect weak floodplain currents. The argillite fragments common in the arenaceous units may have been derived from emerged tidal flats or lagoons when attacked by storm waves or flood waters. The dolomite phenoclasts, described earlier, are probably dolomitized lime muds deposited in a lagoon. The pellets in them could be mud balls fromed by gentle wave action, and if some of the pellets are algal fragments, these would have been rounded by the same process. Since there appears to have been only a slight reworking of the sediments, the deposition site may have been rapidly subsiding.

STRUCTURE

Introduction

The Precambrian rocks of the Jasper area, which lie within the Pyramid thrust sheet (fig. 1), have been folded into a series of anticlinoria and synclinoria, in one of which, the Rathlin Lake synclinorium, lies the Wynd map-area. The regional strike of these fold complexes is north 60 degrees west, while the folds of the map area have an average trend of north 73 degrees west. Deformation, presumed to have taken place during the Laramide orogeny, is chiefly expressed as folding.

Folding

Eight folds, lettered A to H from southwest to northeast for ease of reference, are thought to occur within the map area. Some of these extend northwestward beyond the map area for a distance of several miles, while others can be traced for only a few hundreds of feet (fig. 2). Table 1 shows the average values for the attitude of the axial plane, the plunge, the attitude of the limbs and the horizontal distance between the axial planes of the folds.

Dips on the northeast limbs of anticlines range from 22 degrees northeast to 70 degrees southwest overturned and average 67 degrees northeast. On the southwest limbs of anticlines dips range from 42 degrees southwest to 78 degrees northeast overturned with the average being approximately 65 degrees southwest. While there are local departures from symmetry, the above averages show that the folds are nearly symmetrical (see figs. 2a-d).

Table 1

Fold	Attitude of axial plane		Plunge	Attitude of limbs		Horizontal distance between folds
	Strike	Dip		SW limb	NE limb	
Anticline A	N81°W	75°NE	21°NW	51°	38°	100'
Syncline B	N72°W	72°NE	42°NW	38°	west end 62° east end 88° O.T.	150' to 400'
Anticline C	N77°W N85°W	west end 80°NE east end 60°NE	variable	west end 62° east end 88° O.T.	40° 68°	250' to 400'
Syncline D	N72°W	80°NE	west end 40°SE east end 49°NW	45° 68°	74° 40°	400' to 600'
Anticline E	N58°W N63°W	78°NE	west end 45°SE east end 49°NW	60°	89°	0' to 300'
Syncline F	N70°W	85°SW	19°SE ?	83°	60°	75'
Anticline G	N70°W	85°SW ?	?	60°	82° O.T.	150'
Syncline H	N70°W	80°SW	? NW	85°	80°	

The east end of syncline B, which shows a strong departure from symmetry, has a 54 degree difference in dip between the two limbs. This anomalous situation is attributed to a thrust fault which has been inferred to occur along the eastern extension of syncline D (see p. 35).

The trace of syncline H corresponds to the axis of the Rathlin Lake synclinorium as mapped by Charlesworth et al. (1961, p. 12). Departures of folds from regional strike are probably the result of local variations in competency of the strata, the influence of topography, and possibly to unobserved small scale faulting.

In nearly all cases, the dips of the axial planes of folds were determined from a limited number of cleavage readings which sometimes yielded conflicting information. Where the discrepancy arose between a cleavage reading in argillite and one in sandstone the argillite reading was given preference. The cleavage in the argillite is more planar and better developed than that in the sandstone, hence it probably yields more reliable information. Only at the eastern end of syncline B were there sufficient exposures to allow a detailed study of the fold-cleavage relationship (see p. 38). The regional plunge of the folds, although highly variable, is generally northwest (see p. 38).

The eight folds mapped occur within a distance of 1200 feet, measured from the axis of anticline A to that of syncline H. The distance between axes varies from almost zero, where syncline F dies out against anticline E, to 600 feet between syncline D and anticline E (fig. 2; table 1). The average distance between folds is 160 feet. Structural relief is at a maximum between anticline E and syncline F, where it is approximately 450 feet (fig. 2b). The minimum of approximately 50 feet, occurs between syncline F and anticline G.

Crustal shortening in the lower part of the Miette Formation, in the absence of faulting, is a function of the tightness of folding. Values of crustal shortening obtained for the formation include 32 per cent (Stauffer, 1961) and 35 per cent (Steiner, 1962). These values compare with 40 per cent for the Wynd map-area.

Faulting

Despite the rather severe folding, only two relatively small faults appear in the map area. Others may exist, but owing to discontinuity of exposure and uniformity of rock-type within the map area, they remain undetected. A small thrust in sandstone unit 4 was observed in the railroad cut, 300 feet west of Caledonia Creek. The slickensided fault plane strikes north 17 degrees west and dips 85 degrees southwest (plate VIa); the rake of the net slip is 86 degrees southeast with the net slip nine feet. At the same outcrop, bedding plane slip of unknown magnitude has occurred.

The second fault was not observed in the field but has been inferred to occur as the eastern extension of syncline D (fig. 2). Four lines of evidence support the existence of this fault. These are: (1) the swing in orientation of fold axes A, B and C as they approach the fault; (2) the convergence of folds B and C toward D and their subsequent apparent termination; (3) the strongly overturned southwest limb of anticline C, suggesting rotation about a curved fault plane (fig. 2b); and (4) the tightness of folding in anticline C, indicating a fault or plane of décollement at no great depth beneath the surface. The inferred thrust strikes approximately north 65 degrees west and, at the surface, dips 75 degrees southwest. Relative movement of the hanging wall apparently consisted of rotation about two mutually perpendicular axes, one of which lies along the strike of the fault plane. Rotation about the axis perpendicular to the fault explains the change in strike and the dying out of movement to the west. The anomalous attitude of anticline C suggests rotation about the axis parallel to the fault, the effect being equivalent to that produced by movement along a fault plane

PLATE VI

a. Small thrust fault in sandstone unit 4; looking northwest along the railroad 400 feet west of Caledonia Creek.

b. Looking west - well developed slaty cleavage in argillite unit 5, syncline B.

c. Photomicrograph - thin section of argillite unit 1, showing three foliations. Specimen collected along the railroad near the west end of the map-area. X9

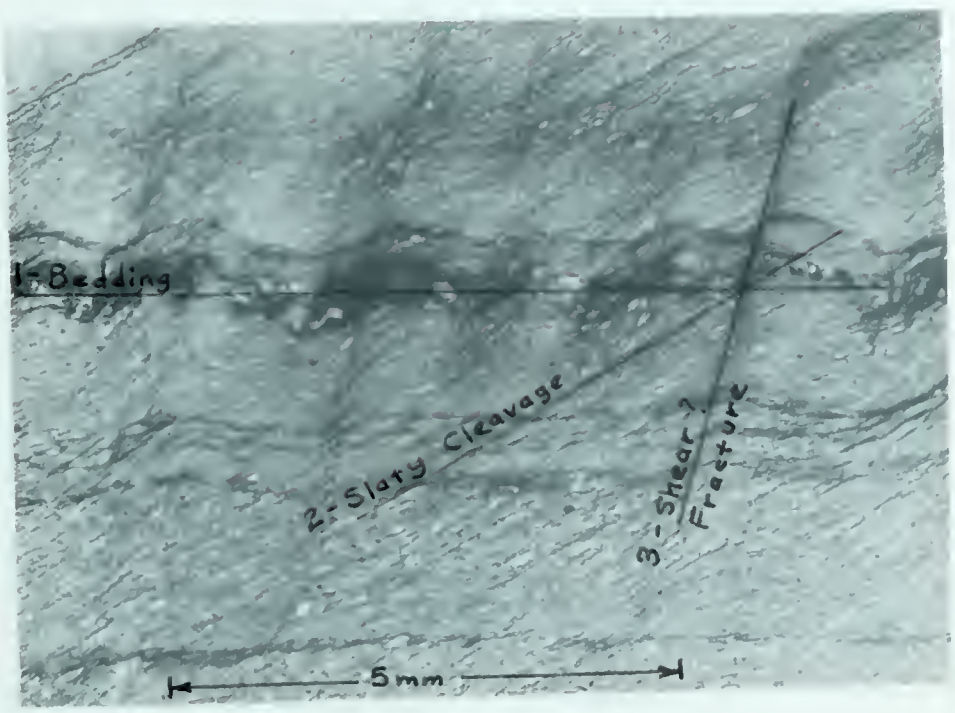
d. Well developed fracture cleavage in fine-pebble conglomerate.



a



b



c



d

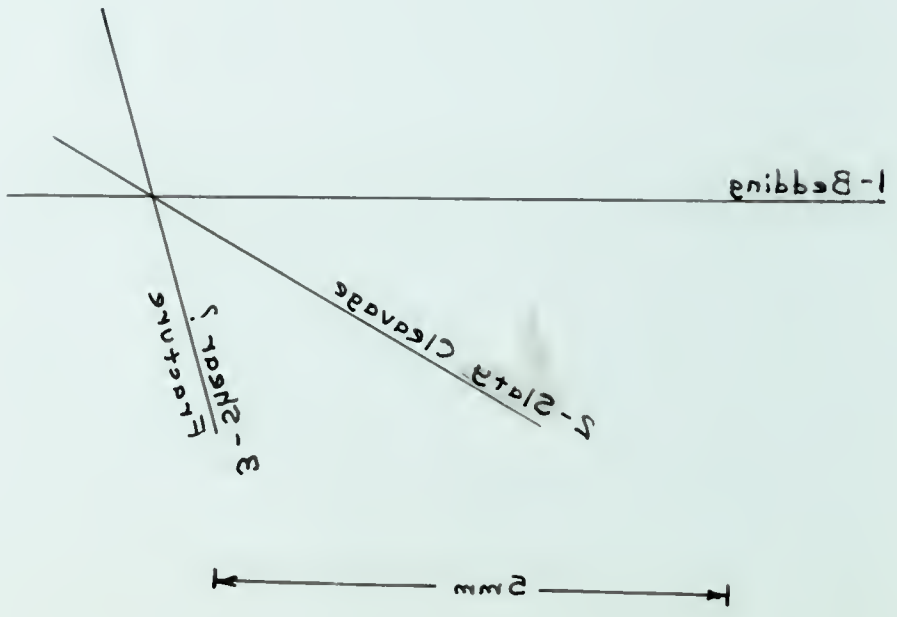
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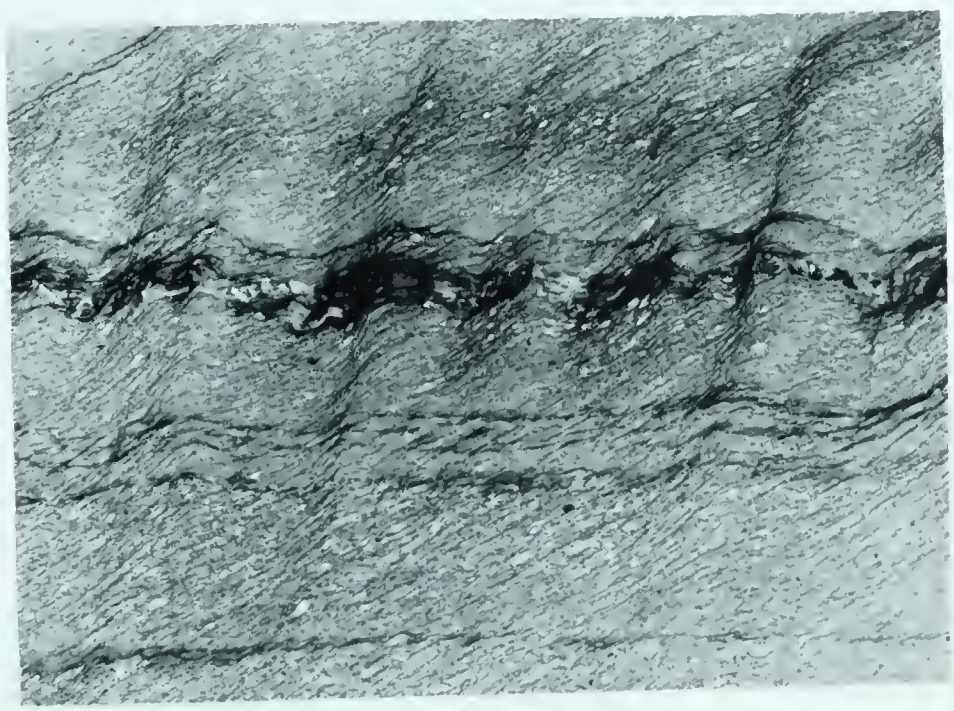




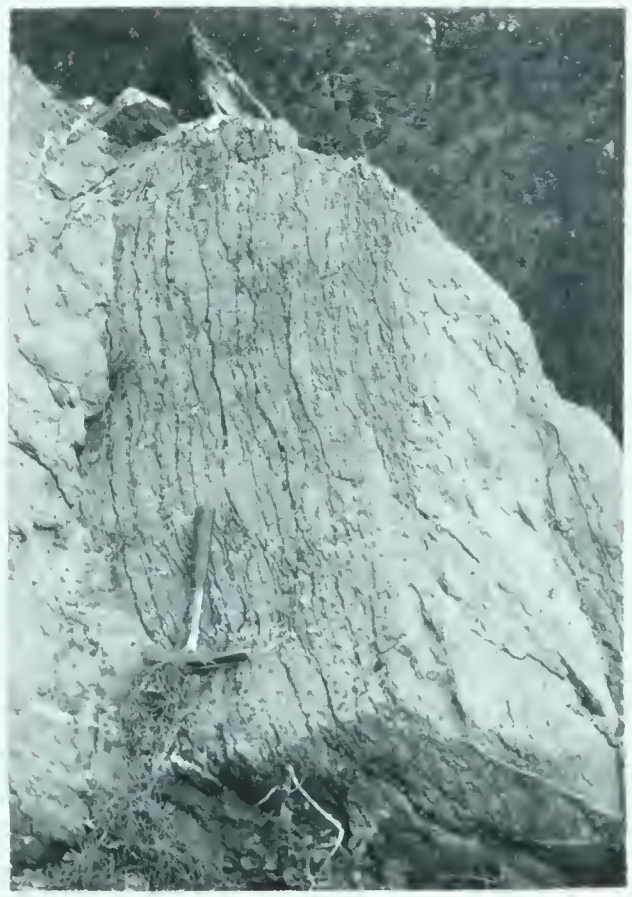
a



b



c



d

concave to the surface. In the subsurface, the fault presumably dies out at no great depth in argillite unit 3 (fig. 2b) which acted as a plane of décollement.

While the thicknesses of individual arenaceous units in the lower part of the Miette Formation tend to remain unchanged across the folds, the argillaceous units have behaved incompetently. This has resulted in the folds being similar rather than parallel. Folding of this type necessitates relative movement between the arenaceous units, which is greatest in the limbs of the fold, and dies-out toward the axes. On the southwest limb of anticline D, relative movement between sandstone units 2 and 4 appears to have taken place along argillite unit 3. With the pinching-out of this argillite, bedding-plane slip was taken up by movement along the fault (fig. 2b).

Cleavage

Slaty cleavage, generally well developed in the argillite units, is presumed to be approximately parallel to the trace of axial planes of folds. Insufficient measurements were made in the field to enable areal study of slaty cleavage, but where measured, its intersection with bedding was used to approximate the direction and magnitude of the plunge of folds. Observed variation in attitude may be the result of a fan-like arrangement of slaty cleavage around a fold (see Cloos, 1947, p. 897). The best developed slaty cleavage is found in argillite unit 5, syncline B (plate VIb).

Fracture cleavage has formed in many of the competent sandstone units, but is often not well developed. An exceptionally good example is shown in plate VId. The fractures resemble small joints spaced one-half to two inches apart. The attitude of fracture cleavage was measured around the nose of

syncline B, in sandstone unit 4 (fig. 7). The intersection of this cleavage and bedding was used to determine the plunge shown on the overlay to figure 7. Due to the rather irregular nature of the fracture cleavage and the weathered condition of the outcrop, individual readings, even when closely spaced, show a considerable range in attitude. Despite this, the overall picture is consistent. The average dip of the cleavage is 80 degrees northwest while the strike, from west to east, swings from north 80 degrees west to north 58 degrees west. As already stated, this swing is attributed to thrust faulting.

Cross section A-A', figure 8, shows the fracture cleavage essentially parallel to the axial plane of the fold. The anomalous dips on the cleavage are most probably due to poor field information since they show no consistent trend. The cleavage shows no tendency to converge downward (cf. Billings, 1954, p. 350) and is parallel to the axial plane of the fold. This suggests that the fracture cleavage did not result from simple shear. A possible mode of origin may be similar to the compression schistosity of Turner and Verhoogen (1960, p. 653). The mechanism for this consists simply of the flow of mechanically weak material into a plane of low shearing stress approximately normal to the compression. Alternatively, the mechanism responsible for the formation of the fracture cleavage may follow Bonorino's (1958, p. 57) proposal for the dimensional orientation of minerals during deformation. In a mixture of spherical quartz grains and elongated mica particles under compression, there is relative shearing displacement between spherical grains according to the inclination of their common tangential plane. Displacement between the grains proceeds in such a manner as to result in "flow" perpendicular to the compression. At the same time, elongate particles are



DIRECTION AND MAGNITUDE OF PLUNGE – SYNCLINE B

(OVERLAY TO FIG. 7)

SYNCLINE B

BEDDING AND FRACTURE CLEAVAGE ATTITUDES

LEGEND

BEDDING

FRACTURE CLEAVAGE

THRUST FAULT

ARGILLITE - UNIT 5

SANDSTONE - UNIT 4

ARGILLITE - UNIT 3

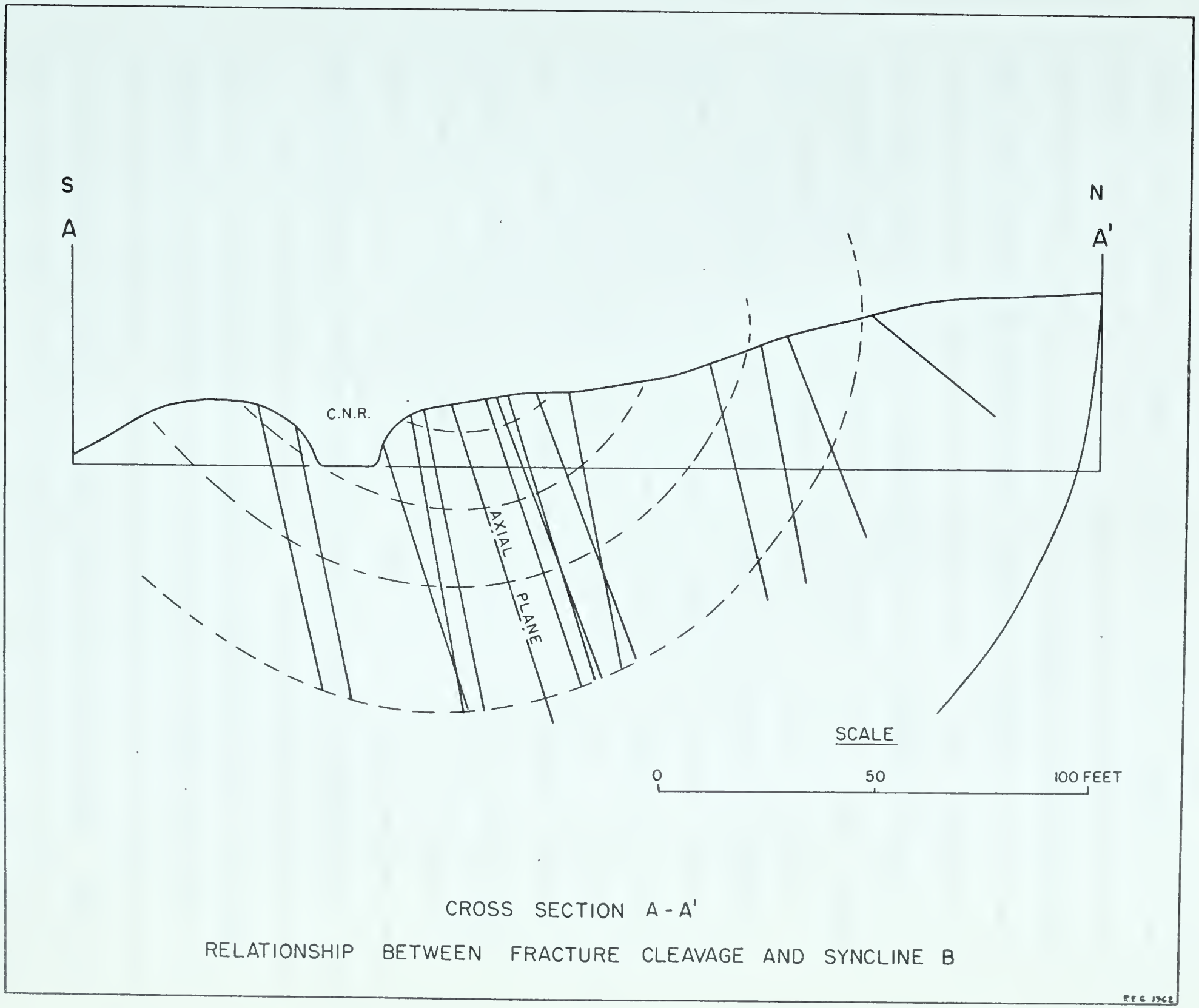
C.N.R

SCALE

0 50 100 FEET

N

Fig. 7



CROSS SECTION A - A'

RELATIONSHIP BETWEEN FRACTURE CLEAVAGE AND SYNCLINE B

REG 1962

Fig. 8

rotated towards a position parallel to the "flow" direction. If recrystallization also occurs, the newly crystallized minerals would be aligned in the same direction. The result of this mechanism is a foliation normal to the compression, which in a fold, would be parallel to the axial plane. Once this plane had formed by either mechanism it would be one of low strength along which fracture could easily occur. In the sandstone of the present study micaceous minerals are not very abundant, hence reorientation and the consequent planes of weakness are not well developed. This may account for the irregular nature of the fracture cleavage.

The magnitude of the plunge as shown on the overlay to figure 8 varies markedly over short distances but generally decreases from west to east. This general decrease may be partly due to a lessening of the dip angle of the axial plane after cleavage had formed, and is in keeping with the rotational nature of the inferred fault. The rapid local variation in plunge is probably due to poor field information since the intersections of cleavage and bedding planes are fairly sensitive to relatively small changes in attitude of these planes. This serves to emphasize that caution must be used before trusting isolated plunge readings measured in the field.

A thin section of argillite unit 1, from a sample collected near the west end of the map area shows three foliations (plate VIc). The primary foliation is a relict bedding which indicates the original orientation of platy detrital minerals. The second foliation, the plane of which contains all the micaceous minerals, is a well developed slaty cleavage. The micaceous minerals have all recrystallized and there has been a marked elongation of chlorite and quartz grains parallel to the cleavage. The tertiary foliation is marked by sharp microfolds along whose axes there has been

minor reorientation of minerals. This could possibly represent an incipient development of shear fractures. It appears that if deformation had continued in this direction, the result would have been both a further reorientation of the grains and rupture.

Jointing

General. Joints are common in rocks of the Wynd map-area especially in arenaceous beds where they are commonly filled with vein material (see p. 50). The attitudes of 221 joints were measured and the poles of these plotted on a Schmidt equal-area net. Most readings were taken from south-west-dipping beds since these are the best exposed. The poles were contoured on the basis of the number occurring in an area one-hundredth that of the net. Since 2.2 poles in each such area would constitute a random distribution, it was decided that 6 poles form a significant concentration. Using this criterion, 8 joint sets have been recognized (fig. 9).

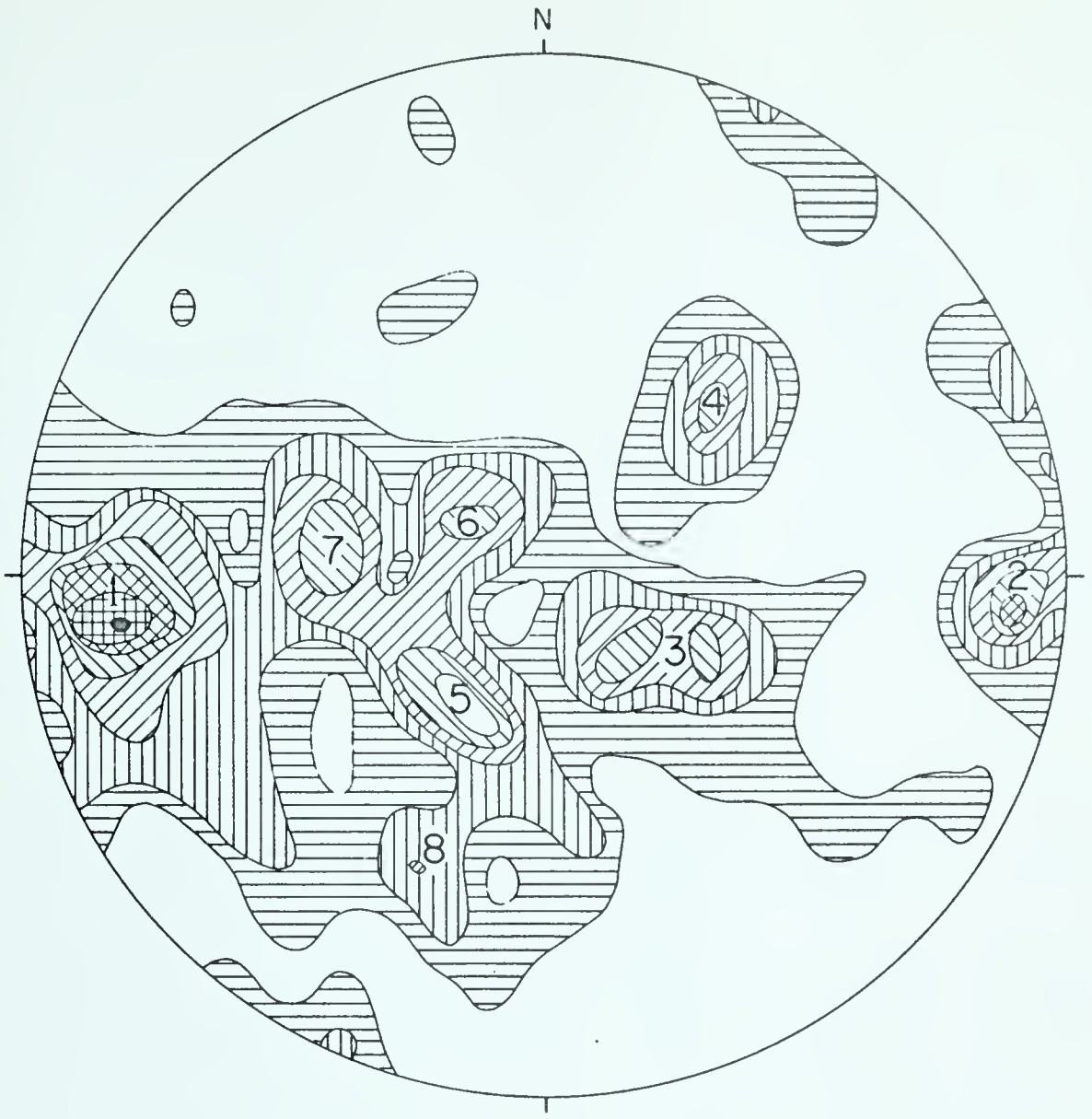
Interpretation. Strong folding, plunging structures, non-uniform lithology, as well as the possiblity of the joints having originated from local rather than regional stress, are probably all responsible for the complexity of the joint pattern. Therefore, the interpretation summarized in table 2 has to be considered as tentative.

Table 2

Joint set	Attitude	Type	Time of Formation
1	N 6° W, 70° NE	Shear Veined & unveined	Early to Late Folding
2	N 5° E, 79° NW	Shear Unveined	Late Folding
3	N 33° E, 22° NW	Shear Veined & Unveined	Early to Late Folding
4	N 45° W, 37° SW	Shear Unveined	Late Folding
5	N 51° W, 23° NE	Shear Veined	Early to Late Folding
6	N 35° E, 15° SE	Tension Veined	Pre- to Early Folding
7	N 11° E, 33° SE	Shear Veined & unveined	Early to Late Folding
8	N 68° W, 50° NE	Tension Veined	Late Folding to Post Stress Release

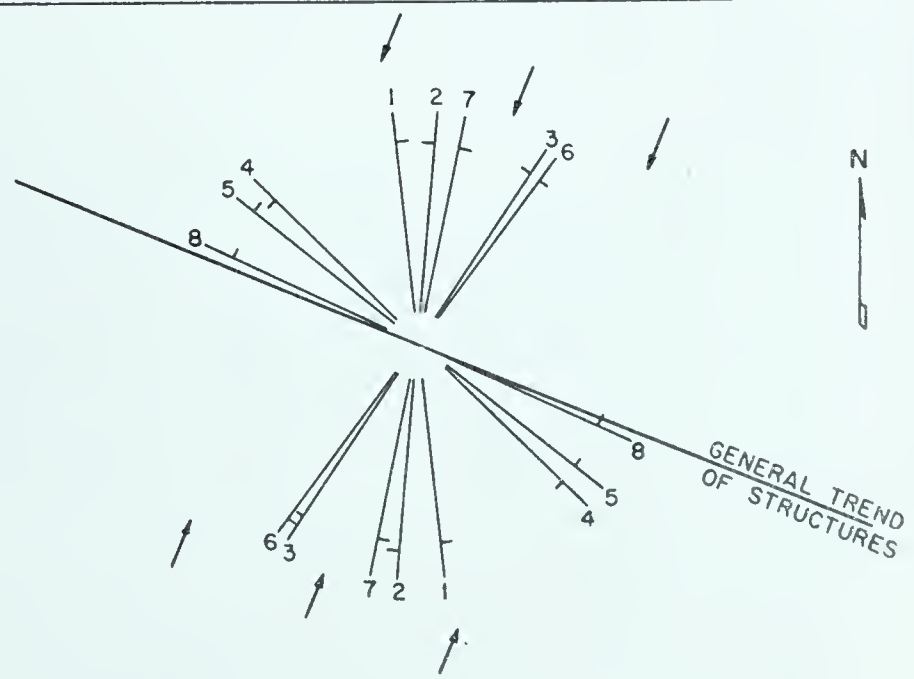
The appearance of the joints (plate VII) and their relationship to the structure (fig. 10), were used to determine the type. A set appearing to contain more than one type was classified after the majority. The time of formation was determined by observing intersections and displacements.

Conclusions. Data for this study were collected by measuring all the fractures on any reasonably well exposed outcrop, regardless of its structural position. It was hoped that a coherent picture of the relationship between the fracture pattern and the stress system would



POLES TO JOINT PLANES
CONTOURED ON A SCHMIDT EQUAL-AREA NET

Fig. 9



RELATIONSHIP OF JOINT SETS TO STRUCTURE

Fig. 10

PLATE VII

a. Joint sets 3 and 4 on the base of a steep NE dipping sandstone bed in unit 2. Looking NW along the railroad 1300 feet west of Caledonia Creek.

b. Joint sets 1, 2 and 6; approximately same locality as above. Other joints in the rock did not form a concentration.

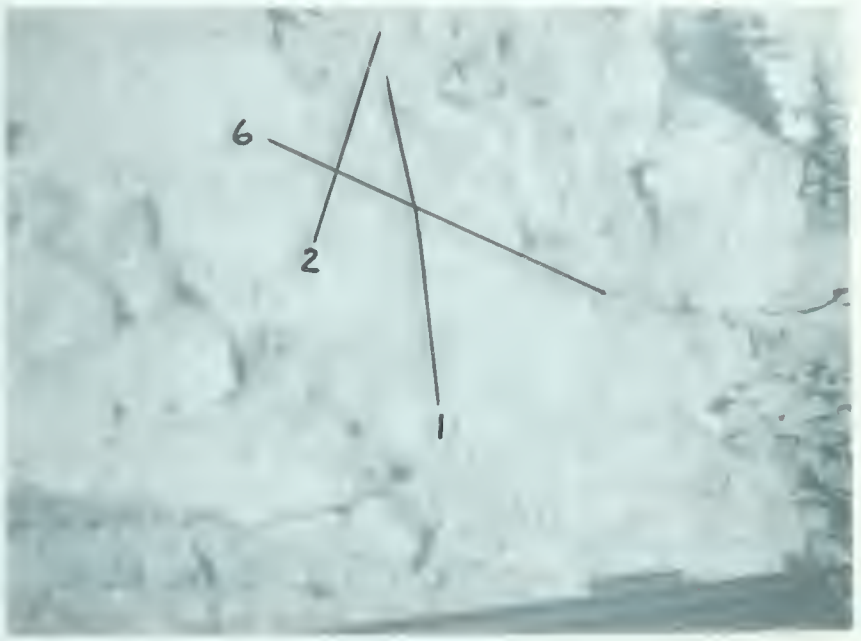
c. Joint sets 5 and 7 in a SW dipping bed of sandstone in unit 4. Looking NE, 500 feet north of the railroad, one-half mile west of Caledonia Creek.

d. Joint set 5 displaces set 7 on the base of a sandstone bed in unit 4. Looking NE, along the railroad 3000 feet west of Caledonia Creek.

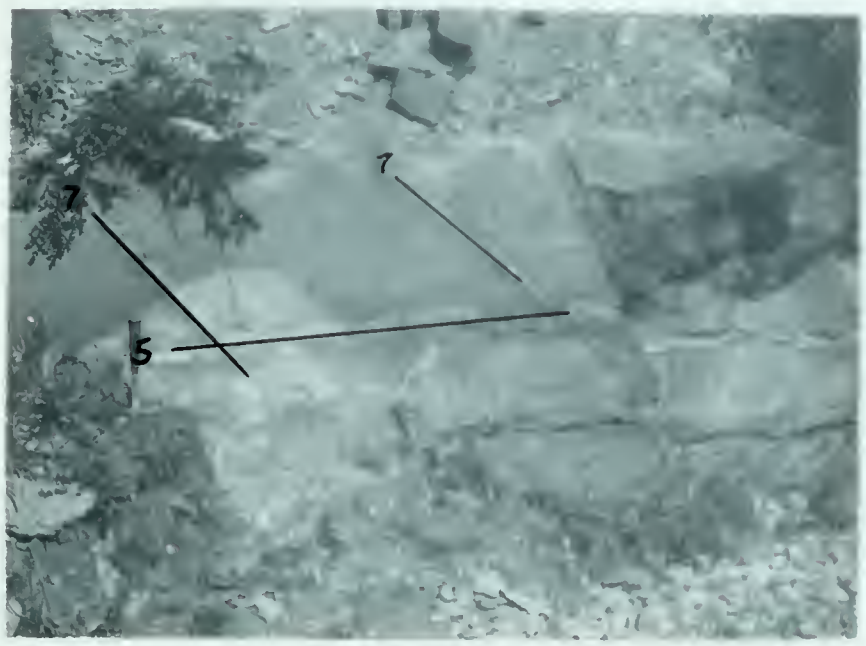
e. Highly veined portion of sandstone unit 4. Late unveined joints can be seen cutting the earlier veins. Looking NE, approximately one mile west of Caledonia Creek.



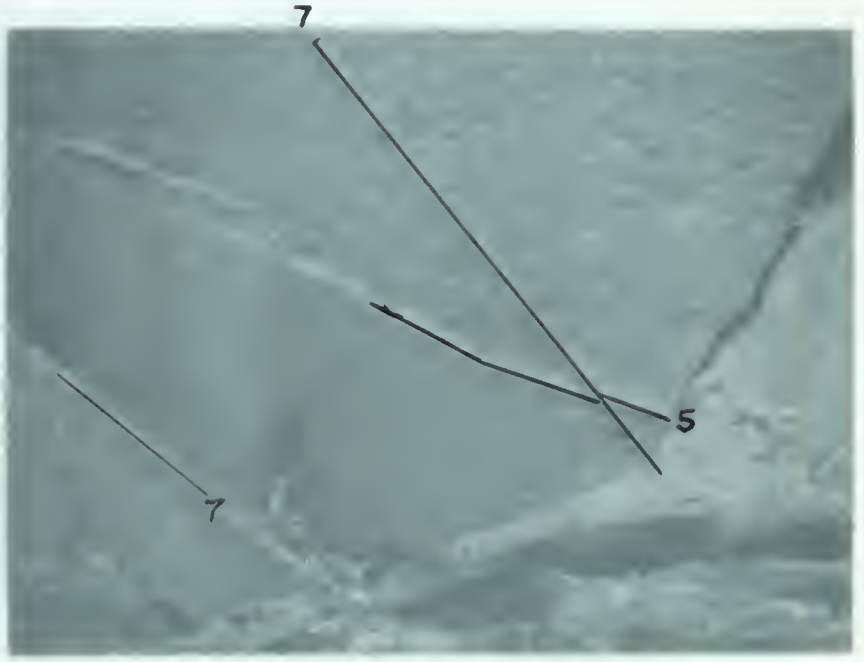
a



b



c

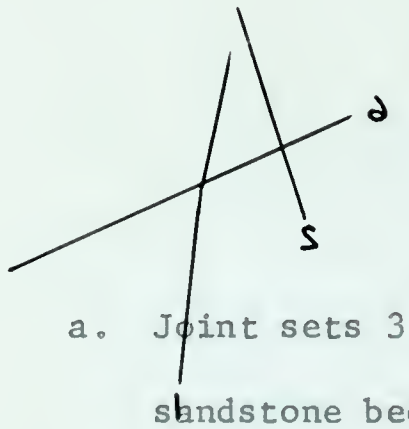


d



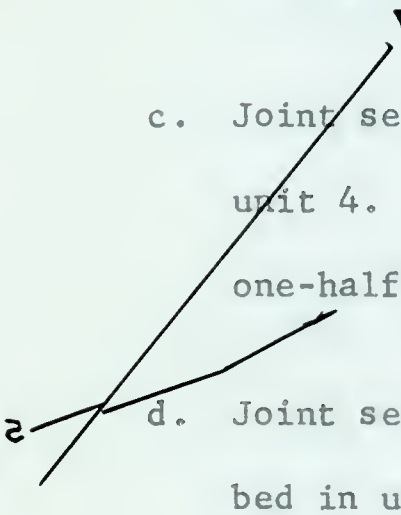
e

PLATE VII

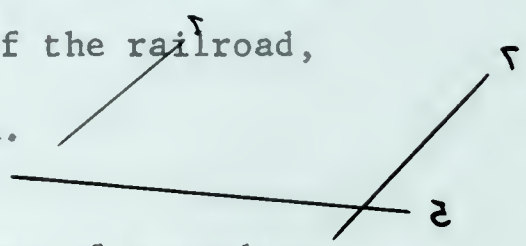


a. Joint sets 3 and 4 on the base of a steep NE dipping sandstone bed in unit 2. Looking NW along the railroad 1300 feet west of Caledonia Creek.

b. Joint sets 1, 2 and 6; approximately same locality as above. Other joints in the rock did not form a concentration.



c. Joint sets 5 and 7 in a SW dipping bed of sandstone in unit 4. Looking NE, 500 feet north of the railroad, one-half mile west of Caledonia Creek.

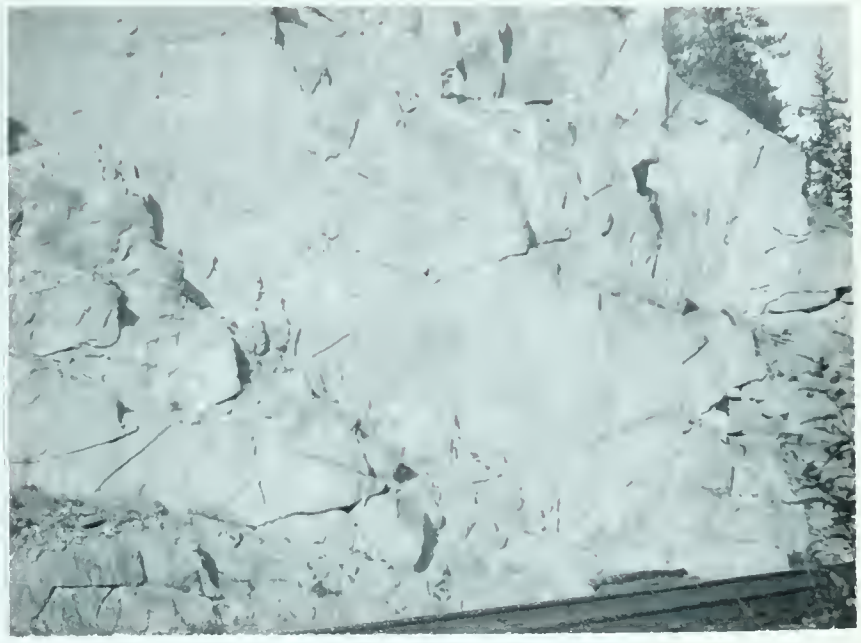


d. Joint set 5 displaces set 7 on the base of a sandstone bed in unit 4. Looking NE, along the railroad 3000 feet west of Caledonia Creek.

e. Highly veined portion of sandstone unit 4. Late unveined joints can be seen cutting the earlier veins. Looking NE, approximately one mile west of Caledonia Creek.



a



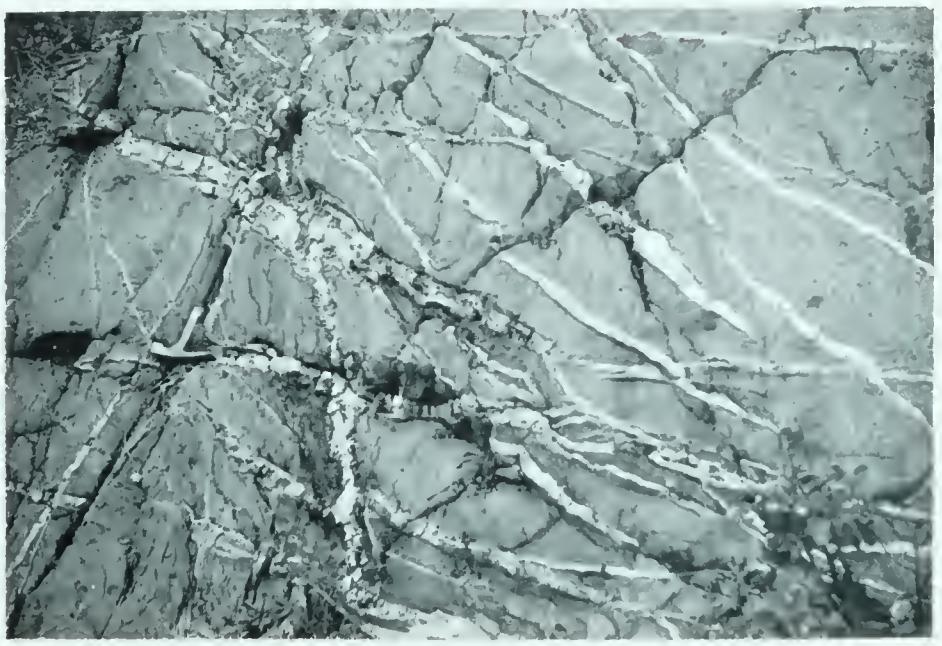
b



c



d



e

emerge. That no clear-cut picture did evolve probably indicates that this was the wrong approach. It appears that there are too many variables in this region to permit the emergence of a coherent pattern. In the writer's opinion, a joint study in this area can be properly interpreted only if it is confined to a single, well exposed fold, where some of the variables would be eliminated and the effects of others directly observable. In this manner, it might be possible to establish a master joint pattern with which isolated joint sets from other areas could be compared.

METAMORPHISM AND VEINING

The observed effects of metamorphism on the rocks of the Wynd map-area differ little from those described in detail by Stauffer (1961, pp. 53-58).

Rock Assemblage

The main constituents of these regionally metamorphosed rocks are quartz, chlorite, muscovite and calcite. This assemblage is characteristic of the quartz-albite-muscovite-chlorite subfacies of the greenschist facies, as defined by Turner and Verhoogen (1960, p. 534).

The paucity of albite in rocks of the Wynd map-area is attributed not to its instability in the metamorphic environment, but to the non-arrival of feldspar from the source area. Of the feldspar present, the two states of preservation - fresh albite and mixtures of fine-grained muscovite and chlorite (see p. 11) - seem to indicate feldspar of more than one composition arriving from the source. Quartz overgrowths indicate that quartz was stable at some stage of metamorphism, but it was probably unstable at others, as indicated by matrix replacing the edges of some of the grains. Chlorite and fine-grained muscovite appear as stable products of a reconstituted clay matrix, and the breakdown of unstable biotite. Most of the calcite was probably deposited in the original sediment as cement. The heavy mineral suite, which shows no overgrowths, was probably metastable. Euhedral siderite and pyrite are stable secondary minerals.

Vein Assemblage

The vein minerals include quartz, calcite, chlorite and a trace of rutile. These minerals are common in Miette strata hence the constituents of the vein minerals were probably derived locally and emplaced during metamorphism. In width, the veins range from microscopic to over 14 inches, most are composed of at least two minerals, but quartz does occur on its own. Pure calcite veins were observed only on a microscopic scale.

Quartz is usually in the form of coarse elongate grains clouded with dusty inclusions. Except for rutile needles associated with subhedral rutile grains (plate 5c), no mineral inclusions were observed in the quartz. Chlorite, conspicuous as green patches in the otherwise white veins, is vermicular in form, pale green in colour, and shows anomalous blue birefringence. Creamy-white calcite, which occurs as pods up to several inches long in the larger veins, is nearly always twinned.

Strained and fractured quartz, twinned calcite, fine quartz grains in the centre of some quartz veins, and unveined joints cutting those veined, indicate that the veins were emplaced during orogenesis over a considerable period of time.

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